Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

Machine learning at the Cornell Electron Storage Ring

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AGS ML collab. meeting: Aug 25, 2023

[1] *special thanks to Jim Shanks and Vardan Khachatryan*

Machine Learning at CESR?

Machine Learning at CESR?

A blank canvas...

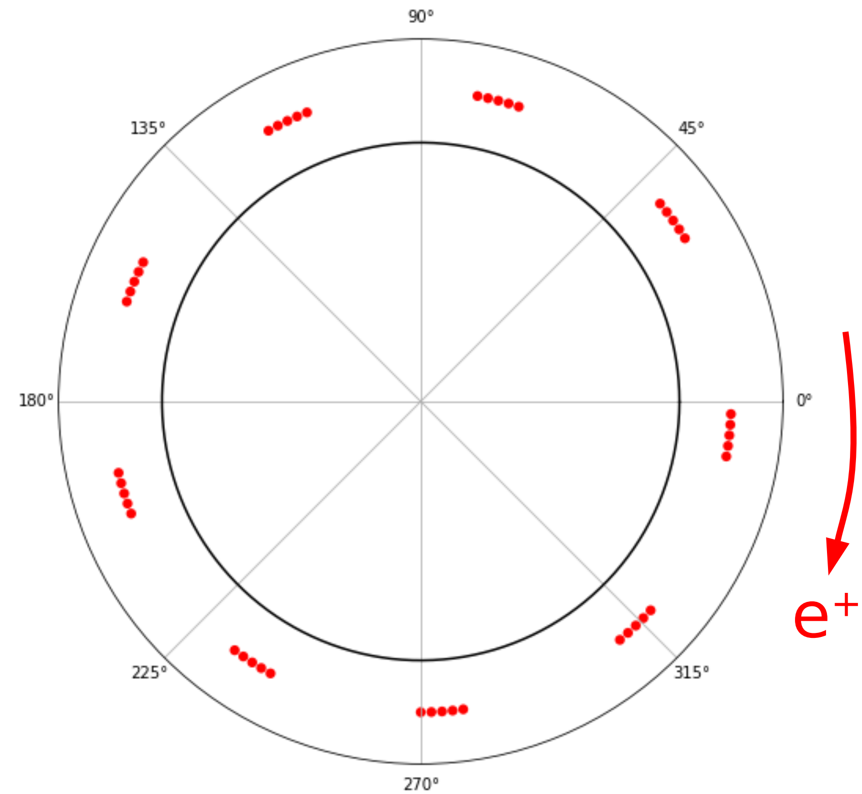
we are just beginning to
learn and explore our options

Cornell Electron Storage Ring (CESR)

CESR is a 6 GeV positron storage ring operating as a bright X-ray source (1 to 200 keV energies) for the Cornell High Energy Synchrotron Source (CHESS)

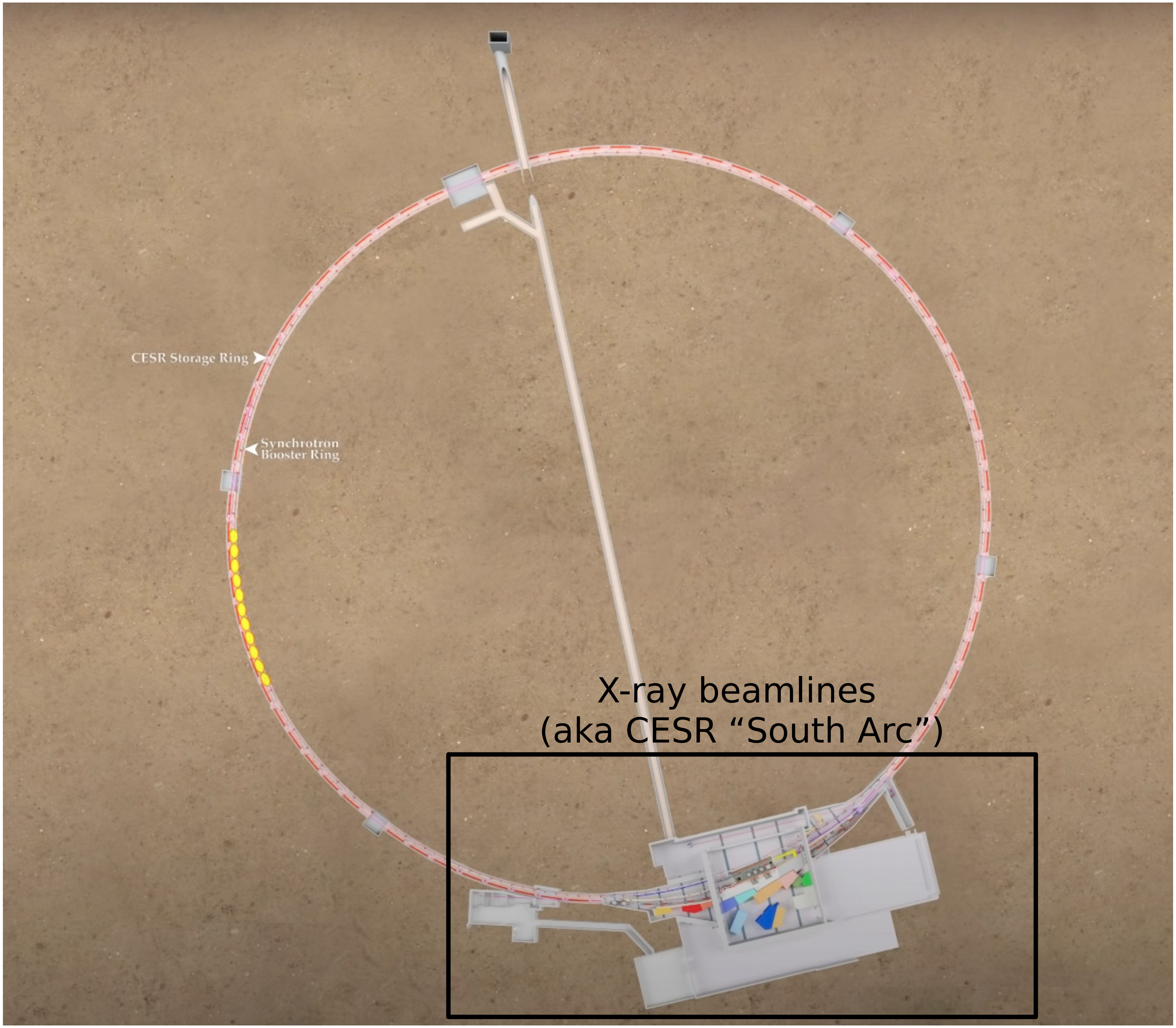
Some CESR facts:

- ✗ 768 meter circumference
- ✗ 2.56 μs revolution period
- ✗ 125 mA total operating current
- ✗ 17 hours beam lifetime
- ✗ 9 trains of 5 bunches
- ✗ 2.8 mA/bunch (7.2 nC/bunch)
- ✗ 224 ns train separation
- ✗ 14 ns bunch separation
- ✗ 100 ps bunch length



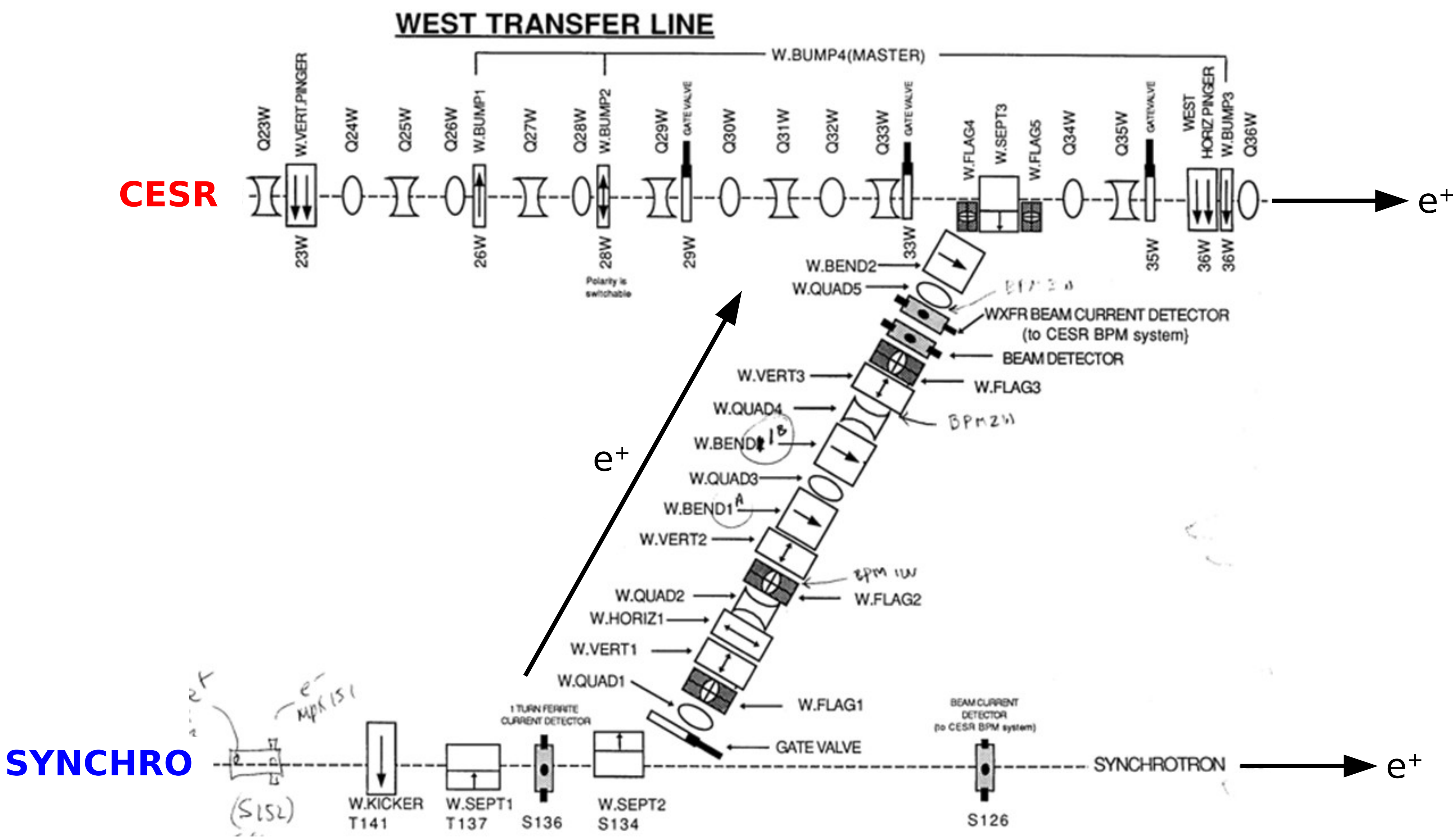
courtesy J. Shanks

CESR


CESR Storage Ring
Synchrotron
Booster Ring
X-ray beamlines
(aka CESR "South Arc")

CESR injection

Injection to **CESR** from **Synchrotron**



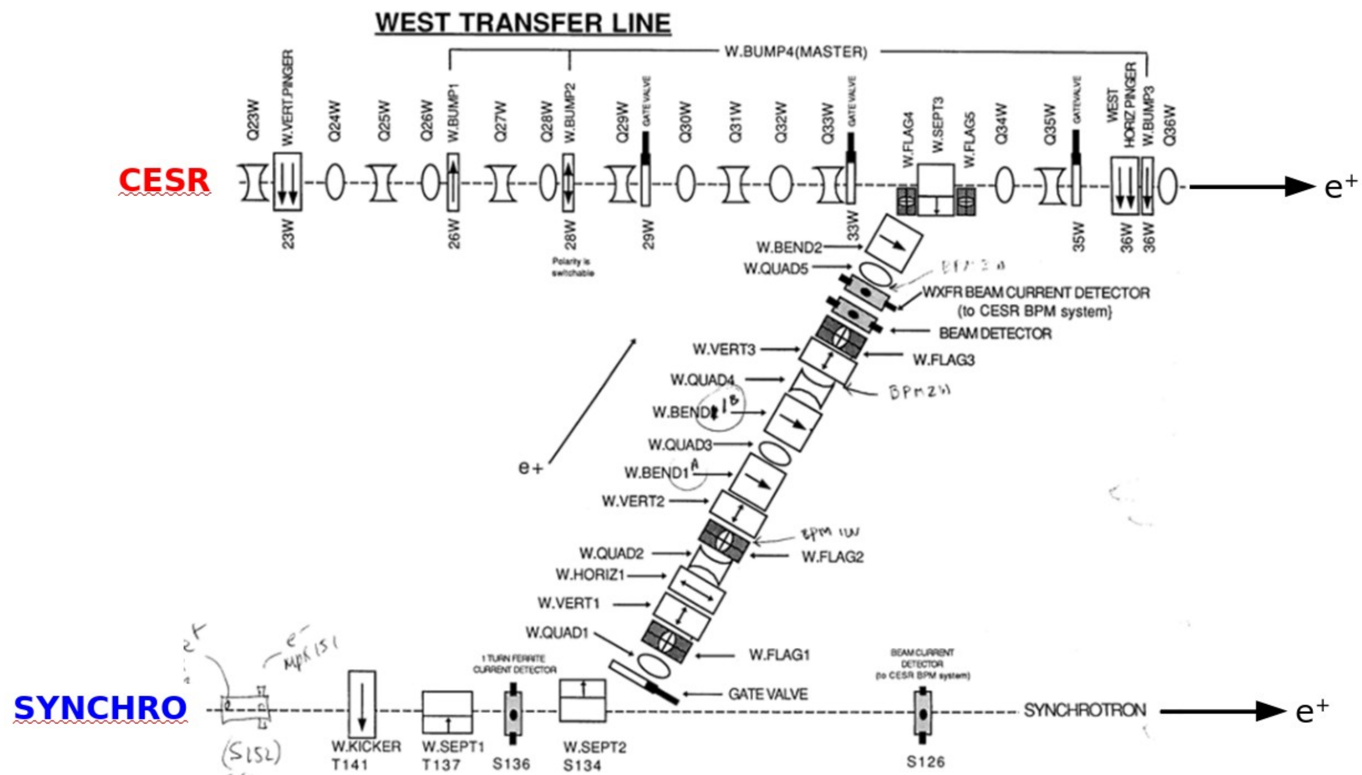
CESR injection

Injection knobs:

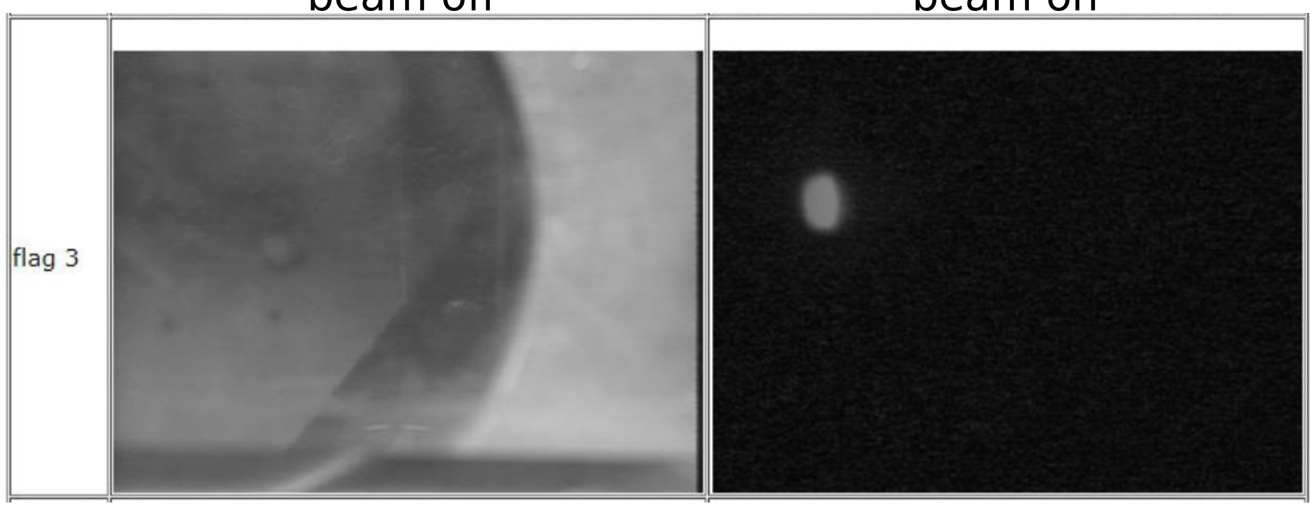
- ✗ synchrotron energy
- ✗ 1 extraction kicker
- ✗ 3 septa
- ✗ 3 vertical steerings
- ✗ 1 horizontal steering
- ✗ 2 bends
- ✗ 5 quads

Instrumentation:

- ✗ 5 flags (destructive)



beam off | beam on



CESR magnets

Magnets connected in series:

- ✗ 70 dipoles (bend) magnets
- ✗ 12 combined function (DQ) magnets

Individually controlled magnets:

- ✗ 113 quadrupoles
- ✗ 76 sextupoles
- ✗ 27 skew quads

Corrector magnets (individually controlled):

- ✗ 74 horizontal (24 in South Arc, 50 in North Arc)
- ✗ 69 vertical (24 in South Arc, 45 in North Arc)

CESR instrumentation

CESR BPM (CBPM):

- ✗ about 100 house-made BPMs located all around the ring
- ✗ orbit measurement
- ✗ phase measurement
- ✗ turn-by-turn capability at all locations (up to 300k turns)
- ✗ any and all stored bunches
- ✗ 10 micron single-turn resolution

Orbit monitoring:

- ✗ full orbitry every minute
- ✗ includes all magnets readback
- ✗ months/years of past data

CESR instrumentation

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CBPM upgrade coming “soon”:

- ✗ 10 Hz continuous orbit monitoring
- ✗ micron-level position resolution (turn averaging)
- ✗ better data/metadata logging

CESR instrumentation

Other instruments:

- ✗ x-ray Beam Size Monitor
- ✗ 10 Libera BPMs (in South Arc)
- ✗ 9 VBPMs (in South Arc)
- ✗ ...

CesrV – by David Sagan

The "Virtual CESR" program CesrV is a general purpose program for simulating CESR. For example, With CesrV you can:

- Simulate the effect of changes in any attribute (position, strength, etc) of any element in CESR.
- Take a betatron phase/coupling measurement or read in an existing measurement.
- Take an orbit or read in an existing orbit.
- Do a "wave" analysis on orbit, phase, or coupling data to find the location(s) where there are orbit, phase, or coupling kicks.
- Find the corrections to the steerings to flatten an orbit.
- Find the corrections to the quadrupole strengths, and/or skew quad strengths needed to correct phase/coupling errors.
- Find the corrections to the sextupoles to correct the phase change with pretzel (This is still in development).
- Load into CESR steering, quadrupole, or sextupole corrections.
- etc.

Machine Learning at CESR?

???

Supervised learning

Unsupervised learning

???

???

Reinforcement learning

???

Machine Learning at CESR?

First meeting about ML was held a month ago:

- ✗ took a “first principle” approach to discuss what ML can offer
- ✗ identified two areas that we want to explore

Anomaly detection using unsupervised learning

Online optimization using Reinforcement learning agent

Anomaly detection

Apply unsupervised learning (dimensionality reduction, clustering, association rules) to multivariate time series → real time anomaly detection would be quite a useful tool to improve operation

Potential applications:

- ✗ beam stability (currently a high priority effort)
- ✗ subsystem data quality (CBPM, magnet etc.)

Besides anomaly detection: could we learn new behaviors and relationships?

Potential road blocks:

- ✗ quality of data
- ✗ non-stationary time series
- ✗ autocorrelation in time series

Online optimization

Could we train a reinforcement learning agent to learn and optimize CESR?

Potential applications:

- ✗ orbit correction
- ✗ online optimization (dynamic aperture, injection efficiency, lifetime...)
- ✗ new type of correction/optimization?

Training steps:

- ✗ using CesrV/BMAD, we could pre-train the agent to know “perfect world” CESR
- ✗ using historical orbit monitoring, train agent for real world imperfections
- ✗ deploy optimizing agent which continues training on-the-fly

Training requires a meaningful and balanced reward, e.g.: flatten the orbit but not at the cost of pushing magnet strengths to their limits or decreasing lifetime

Open discussion...

Thoughts/comments?

Other ideas?

Bayesian vs Reinforcement learning for online optimization?

CESR as an ML testbed for AGS, EIC...?

Additional materials